THE California WATER ATLAS

5788

Daniel O. Holmes
March 18th, 1980

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GOVERNOR

State of California
GOVERNOR'S OFFICE
OFFICE OF PLANNING AND RESEARCH
1400 TENTH STREET
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October 24, 1979

Dear Reader:

The California Water Atlas is considered by many reviewers to be the State's most ambitious cartographic undertaking. A staff of researchers, cartographers, and graphic artists worked for over a year and a half to assemble and portray information about water in California. Their efforts were immeasurably aided by a large and dedicated group of advisors, many of whom also contributed narrative portions to the Atlas.

The goal of all this work was to produce a book that would introduce Californians to the complex and compelling issues of water in this state, giving them the information they need to participate more actively in the decisions that governmental agencies make.

In an undertaking of this size, it is inevitable that some inadvertent errors will occur. Such an error appears on page 64, paragraph 3, in which we attempted to summarize a complex legal case which was ultimately decided by the Supreme Court. The statements in the paragraph were derived in part from California Water: A New Political Economy by Merrill R. Goodall, John D. Sullivan, and Timothy DeYoung (Allanheld, Osmum/Universe Books, New York, 1978). The paragraph, which was not intended to imply any wrongdoing on the part of the J. G. Boswell Company, should read as follows:

> The Salyer Land Company brought suit against the Tulare Lake Basin Water Storage District after its property was flooded in 1969. The flood damage could have been reduced and Salyer's property partially protected, had additional Kern River flood water been diverted into the Buena Vista Lake Basin. This would have caused flood damages to agricultural operations in Buena Vista Lake, then leased by J. G. Boswell Company. The flood storage servitude of Buena Vista lake basin, asserted by Salyer, and the District's authority to prosecute a suit against the Kern River interests, were disputed by Boswell and others. Since Boswell held a majority of the votes within the District, the District's board of directors never sought to force the Buena Vista District to take the flood water.

Because of the widespread interest in California water issues and the large demand for the Atlas, we expect it will be necessary to reprint additional copies. In order to keep the document as current, accurate, and useful as possible, we would appreciate your comments and suggestions.

Please send your letter to: The California Water Atlas: Comments
Office of Planning and Research
1400 Tenth Street, Room 206
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Sincerely,

Deni Greene

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Acting Director

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THE California WATER ATLAS

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ACKNOWLEDGMENTS

The list of contributors in this volume identifies the authors of the narrative sections as well as the two principal cartographers on the project. In addition to these individuals, however, the atlas owes its existence in large part to the efforts of Judith Christner, Mark Goldman, JeanAnne Kelley, Peter Vorster, and the other members of the staff as well as to the distinguished members of the advisory group, all of whom gave far more of themselves to this project than anyone could have asked. Each phase of the project profitted as well from the advice and assistance of scores of people throughout the state who gave freely of their time and expertise because they believed the result might prove worthwhile.

The graphic and narrative elements of the atlas were checked and rechecked by the staff of the Department of Water Resources. The responsibility for coordinating this massive undertaking rested with Glenn Sawyer, whose grace and good judgment made all things possible. In addition, several members of the department's staff proved to be invaluable resources for much of the information included in this volume: special thanks are therefore due to Dick Fields, Bob Ford, James D. Goodridge, Chuck Howard, Norman A. MacGillivray, Jim Morris, Charles Pike, and Maurice Roos. The project itself would probably never have come into being, however, without the unstinting and enthusiastic support of Ronald B. Robie, Director of the Department of Water Resources, whose good counsel and devotion to public service shaped the volume from the very beginning.

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The publication of a book of this kind proved to be a new experience for state government. We might easily have gone astray without the expert advice of numerous professionals in the publishing industry. Special thanks in this connection are due to Jon Beckmann, William Kaufmann, Luther Nichols, Ralph Raymer, and Jeremy Tarcher. We owe a special debt as well to William Loy and Lidia Selkregg, whose experience in developing atlases of their own in Oregon and Alaska helped us avoid many pitfalls; to James F. Clements of George Rice and Sons, whose insight and commitment to excellence in the printer's craft did so much to make the atlas a source of pride for us all; and to George Roth of the California Department of Justice, who helped to steer us through the thickets of copyright law.

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Finally, sincerest thanks are due to the families and friends of the staff members on the project whose patience and support helped to sustain each of us through the long hours the atlas demanded.

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Foreword

This book sets out to tell the biggest story in the richest and most populous state in the Union. Water lies at the basis of the modern prosperity of California, and the history of the state is in large part the history of water development. The problems of water supply and delivery for the future are emerging among the critical issues facing not only California but the entire American Southwest over the next ten years. And yet, at a time when environmental consciousness is high and complex problems of world energy supply and international finance are part of the normal fare in our daily newspapers, water remains probably the least popularly understood of our natural resources.

There are good reasons for this. Water is an immensely complex subject which requires the mastery of many disciplines ranging from the practical sciences of hydrology, engineering, and chemistry to an understanding of history, social organization, and the law. The literature available on the subject is vast, but most of it is highly technical in nature, useful only to those who are already working in the field. In a state which was built on water, we lack even a history of water development. As a result, the interested citizen has had few places to turn for a basic understanding of the critical, water-related issues facing California and the West in the balance of this century.

The atlas has been developed as an attempt to correct this problem by providing the average citizen with a single-volume point of access to understanding how water works in the State of California. The reader will find here treatments of every aspect of water supply, delivery, and use in California—the nature of the water environment, the changes mankind has made in that environment, the history of water development, the operation of the major natural and artificial water systems of today, the relationship of water pricing to water consumption, the uses of water in industry, recreation, and energy development, the problems of water quality, and the current and emerging questions of water policy for the future. The atlas will not answer every question the reader may have. In fact, if our work has been done well, the reader should emerge after completing this book with many more questions than he ever thought to ask before. The atlas can, however, establish a context for understanding how those questions should be posed and where to turn for the answers. And it is by prompting this kind of inquiry that the atlas will succeed in its ultimate purpose of enhancing the opportunities for the people of California to take a direct role in shaping public policy in this critically important area.

The California Water Atlas is the product of a 15-month project sponsored by the Office of Planning and Research in cooperation with the Department of Water Resources. A team of researchers based in the Office of Planning and Research assembled the basic data and detailed information for the preparation of maps from a wide range of local, state, and federal sources throughout the state. This material was then relayed to a team of cartographers assembled at California State University, Northridge, where the finished maps were developed. The narrative sections were prepared by experts in each of the many topics treated in the volume. And the project as a whole operated under the guidance and supervision of an advisory group composed of the most prominent figures in the fields of hydrology, engineering, history, book design, environmental protection, and water law.

The result is not a conventional governmental publication. The sheer heft, size, and sophisticated printing of the volume makes that self-evident. These physical characteristics of the book were dictated by the complexity of the information presented in the maps and other graphic elements. What is more important in distinguishing the atlas from other governmental publications, however, is the absence of policy recommendations. We recognized at the outset that if the atlas ever concluded on any point by saying "therefore" then we would have failed in our central purpose of providing a common basis for understanding which leaves the individual reader free to draw whatever conclusions or raise whatever questions seem most appropriate.

The maps and other graphic elements contained in the atlas are likely to be far more densely packed with information than most readers are accustomed to encountering. The model of California's hydrologic balance on the facing page, which effectively combines in one place all the many aspects of water treated in detail throughout the pages that follow, is probably the most complex piece of design anywhere in the book. An attempt has been made in the design of each of the full-page plates, however, to make them susceptible of being read at several levels of detail. In other words, each plate should readily convey some central relationship or aspect of water upon a quick perusal. The three principal colors used in the design of the hydrologic balance, for example, display the relative proportionality of the volumes of water involved in each of the major parts of the system as a whole. For the serious student of water, for applications by the specialist, or for use in the classroom the plates reveal a wealth of information and precision which should, hopefully make a close reading of them an adventure in seeing and understanding.

The quality of these graphic materials is related directly to the nature of the atlas as a whole and the subject it treats. The plates are not designed simply to illustrate the points raised in the text; nor has the text been prepared simply as a helpful companion to fill out what might otherwise be only a picture book. Instead, the narrative and graphic elements of the atlas have been developed as equal partners which the design of the volume as a whole must make to work together. The topics selected for treatment in the plates are those which can be presented most effectively in a graphic form. The information contained in the design of the hydrologic balance, for example, would require pages and pages of charts and graphs to be treated narratively, and it is doubtful that the reader at the end of such a treatment would be able to grasp the relationship between the many parts of the hydrological balance and the way in which these parts fit together as readily as is conveyed in this single image. By the same token, if some aspect of the water system can be just as well described by a sentence or paragraph, then it has been left to the narrative. In this way, we have attempted to provide within the atlas a model of the ways in which advanced cartography can be used as a medium for conveying complex information on issues of public policy.

A friend of mine in hydrology once described the construction of a dam as man's ultimate way of thumbing his nose at God. Certainly the story of the development of the modern water system in California presents one of the most massive rearrangements of the natural environment that has ever been attempted. The book, therefore, begins with a detailed examination of the nature of the original water endowment as a way of establishing an understanding of the limits it placed upon human settlement. The subsequent sections treat the ways in which these limits were confronted and in most cases overcome through the construction of the various principal components of the modern water system. The water system of today, however, is not simply the inevitable result of the natural water endowment. Rather, each of the major artificial water delivery systems developed out of specific historical circumstances and were designed to address particular problems. The first half of the volume, by treating in sequence the development of these systems, thus deals essentially with the question of how things got to be the way they are today. The balance of the volume, beginning with the section on the modern water system, examines how things work today, the ways in which water is used, the problems that result, and what the modern water system can and cannot do.

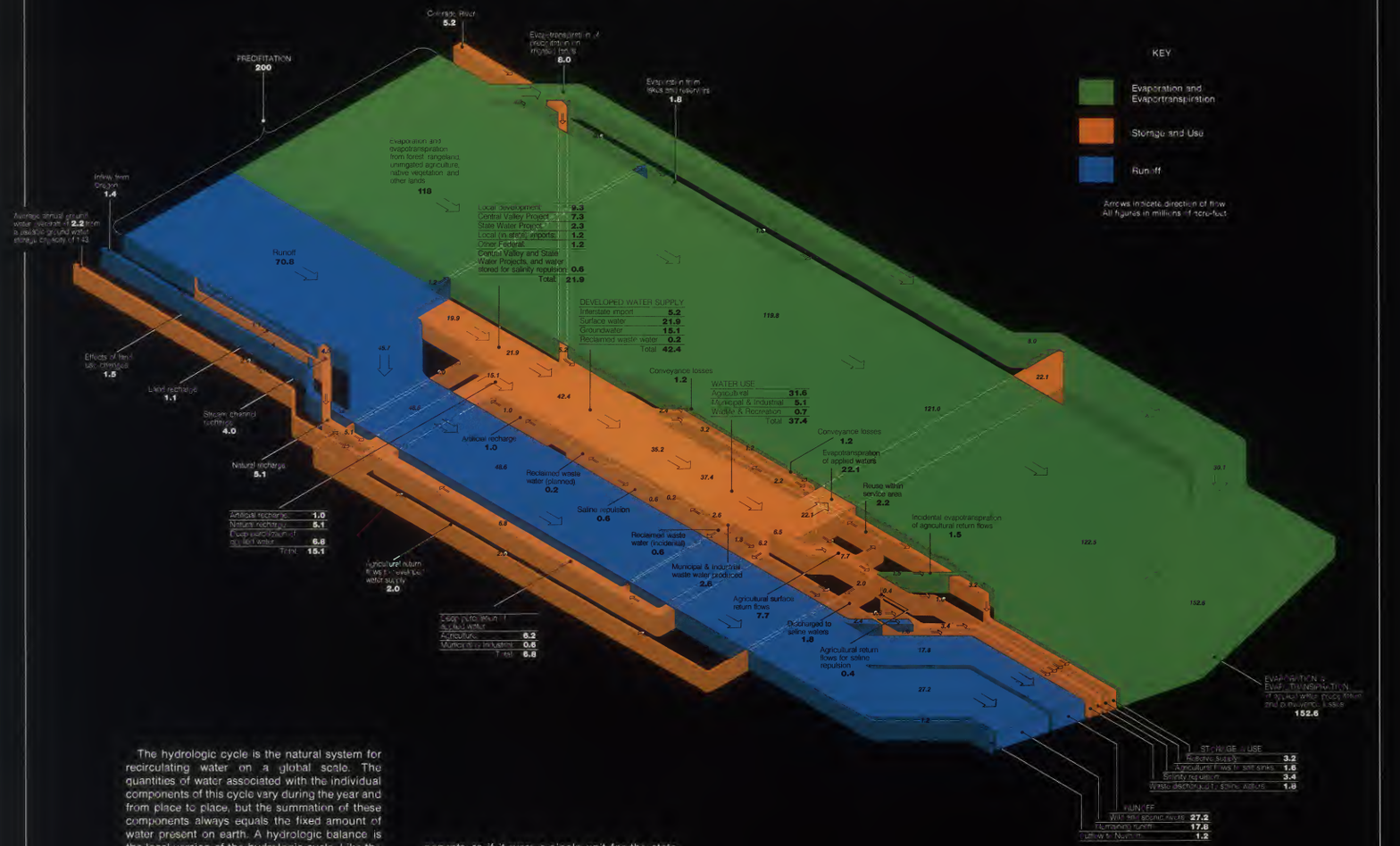
Inevitably in a volume which attempts to treat so vast a subject in so brief a space there will be disagreements as to which topics to bring up and where the emphasis should be placed. The project was conceived from the beginning as a cooperative venture and the book that has been produced as a result is a reflection necessarily of the special talents and interests of the authors, advisors, and staff members involved. Had any one of the more than 50 people who ultimately had a hand in shaping the volume been different, the atlas itself would have been changed.

The cooperative nature of the enterprise was represented most clearly in the development of the narrative. Once we had agreed upon an outline of the book, we divided the topics to be covered according to the expertise of the authors we had selected. As a result, each of the chapters that appear in the volume is made up of parts prepared by several different hands. And all of the original manuscripts were substantially revised and edited to establish a consistent style and tone, to fill in missing elements, and to provide the connectives which knit the pieces together into a whole. Nevertheless, each author approached the topic assigned with his or her own perspective and sense of priorities. As a result, the reader should be able to detect the sound of many voices running through the narrative, and this diversity was felt to be healthy to the extent that it provides a sense of the multiplicity of viewpoints that exist with respect to the various aspects of water in California.

There were, of course, constraints of time, available space, and subject matter imposed on what we could do. In developing the plates, for example, we began with a list of all the subjects we wished we could treat and then began to reduce that list based upon the information that was actually available. Hydrology, as the experts often say, is an inexact science. Cartography, however, is a most exacting art form. If you are preparing a narrative and have 95 percent of the information on the topic being treated, you can safely write a conclusion; but if you are preparing a map of California and have data for every community but one, you might as well have nothing at all.

There is more information available on water through the federal, state, and local agencies used in this project than exists on probably any other topic. And yet, a surprising amount is incomplete, inconsistent, or inaccurate. In addition, there is substantial disagreement between agencies as to methods of reporting, systems of calculation, and even the names of places and facilities.

Hydrologic Balance for California



The hydrologic cycle is the natural system for recirculating water on a global scale. The quantities of water associated with the individual components of this cycle vary during the year and from place to place, but the summation of these components always equals the fixed amount of water present on earth. A hydrologic balance is the local version of the hydrologic cycle. Like the hydrologic cycle, average annual quantities are commonly employed to express the magnitude of the separate components of a hydrologic balance. From these values a hydrologic balance can be calculated for the earth's land surfaces, for the oceans, or for smaller systems such as an individual state or drainage basin. Unlike the hydrologic cycle, however, a hydrologic balance is not presented as a closed, recirculating system but involves instead the combination of natural processes which can be designated as input, storage, or output. The summation of storage and output in a hydrologic balance will always equal the total input.

Normally, precipitation is the principal source of the natural supply of water. In California, however, the input from precipitation is augmented by comparatively small amounts of water derived from the overdraft of the state's groundwater basins, inflows from Oregon, and diversions from the Colorado River. The width of the arrow on the left side of the graphic is scaled to portray the 200 million acre-feet of average annual precipitation received by California. The width of the arrows for supplemental inputs and other components of California's hydrologic balance have been scaled proportionately. The disposition of inputs can be traced as the water moves from left to right in the graphic. California's hydrologic balance, however, is a complex system of components which vary greatly across the state and throughout the year. This graphic simplifies the complexity of the system by portraying each of the principal components as if it were a single unit for the state. Quantities shown for each component are the average annual magnitude of water associated with that function or process.

When precipitation arrives at the earth's surface it is allocated to various outputs and forms of storage by an environmentally controlled priority scheme. Depletion of the input from precipitation occurs within three major categories: return flows to the atmosphere, storage and use, and runoff. The natural demands for evaporation and evapotranspiration receive first priority in this natural scheme, and return flows of moisture to the atmosphere by evaporation and evapotranspiration account for approximately 76 percent of the precipitation input. Most evaporation and evapotranspiration occur from natural land and water surfaces and from nonirrigated agricultural land.

Computation of the hydrologic balance for California, however, requires consideration of the effects of human modifications of the hydrologic environment. For example, irrigated agriculture increases evapotranspiration and reduces runoff while asphalting land surfaces reduces moisture infiltration and increases runoff. The evapotranspiration of water used for irrigated agriculture and urban purposes accounts for 15 percent of the total depletion of input which is attributable to evaporation and evapotranspiration. In addition, many of the various components of the hydrologic balance are linked and some categories of water disposition are consequently not necessarily mutually exclusive. Water allocated originally to a specified use, as in the State Water Project, for example, may be largely evapotranspired or a portion may become runoff. On the other hand, moisture returned to the atmosphere by evapotranspiration from a forest is not available to become runoff or to be applied to some further use.

The disposition of water for storage receives second priority in the natural operation of the hydrologic balance. Water may be stored as soil moisture or in glaciers, snow, lakes, and groundwater basins. A number of alternatives, however, operate among the different forms of water storage. Glaciers and snow, for example, store water temporarily at the surface. After melting, some of this water may be evaporated, some may become runoff, and some may enter another form of storage by infiltrating into the soil to be retained as soil moisture or by percolating deeper to recharge groundwater storage. In computing the hydrologic balance as shown here, soil moisture storage and groundwater storage were not included because net changes in annual soil moisture levels occur only during extremely arid years, while net changes in groundwater storage are indicated by the average annual overdraft that is shown as a supplemental input.

Runoff, the principal source of water for human use in California, is the third priority for disposition of the input to California from precipitation. Consequently, runoff receives only those residual amounts of precipitation which remain after evaporation, evapotranspiration, and natural storage requirements have been satisfied.

The magnitude of all the storage and use components is small when compared with the magnitude of evaporation and evapotranspiration. A summation of the components of the storage and use category is provided by the developed water supply figures. In-state development represents 39.2 million acre-feet but 56 percent of the developed water is consumed ultimately by evapotranspiration. Only 3.2 million acre-feet is retained as a developed water reserve while flows into salt sinks and runoff total 4.4 million acre-feet of developed water. Depletion of the inputs produces a residual of 51.4 million acre-feet of total runoff. The state-generated portion of runoff is slightly less than 50 million acre-feet, but only 27.2 million acre-feet is unencumbered runoff.

These differences, for example, proved determinative in the decision to prepare the atlas using traditional units of measurement. Probably no subject was debated as vigorously by the advisory group as the question of metrics; but when we found that the major water agencies had still not agreed upon what the metric units for the measurement of water will be, we felt we had no choice but to proceed as we have, providing metric conversions wherever appropriate.

In preparing this volume, we have consequently had to resolve many differences of this kind and fill in numerous gaps in the available data with research of our own. The result may be the most comprehensive assembly of information on water in California that has ever been available to the public. Whether we have succeeded in this lofty objective or not, the effort itself establishes a value for the project which is greater than the subject matter involved. For, we began with the assumption that it is a valid public service to take the vast quantities of information government collects and turn it back to the public in a readily accessible form in order to enhance public understanding of the problems we must confront together. And our success in this greater endeavor will be measured not by the volume itself but by the uses to which the reader puts it in the years ahead.

William L. Kahrl
Sacramento, 1979

Glossary

ACRE-FOOT. A standard measurement of volume equivalent to the amount of water required to cover one acre one foot deep. One acre-foot is approximately the amount of water that the average family of five uses in one year, including lawn and garden irrigation.

APPLIED WATER DEMAND. The quantity of water delivered to the user at the point of use, exclusive of any water lost in transport to that point.

AQUIFER. Any geologic formation of sufficient porosity and permeability to store, transmit, and yield water to wells and springs. An aquifer which is surrounded by impermeable materials is a confined aquifer.

ARTESIAN WELL. A well tapping an aquifer in which the water level will stand above the bottom of the confining bed of the aquifer because the hydraulic pressure of the water in the aquifer is greater than the force of gravity. Where the water rises to ground level, a flowing artesian well is created.

BASE FLOW. That portion of the discharge of a stream or river that is not attributable to runoff from rain or snow. Such a flow may be sustained by drainage from natural storage.

BENEFICIAL USE. A use of water for some economic or social purpose. The specific identification of beneficial uses may vary with locality or custom, although the term is most frequently defined by statute or court decision. The State Water Resources Control Board recognizes 21 beneficial uses of water and establishes the levels of water quality required for each.

BIOCHEMICAL OXYGEN DEMAND. The quantity of oxygen used in the oxidation of organic matter in water in a specified time, at a specified temperature, and under specified conditions.

BLOWDOWN. Water discharged from a boiler or cooling tower to dispose of accumulated salts. Also, the removal of a portion of any process flow to maintain the constituents of the flow within desired levels.

BYPASS. A channel used to divert flows from a mainstream, as for the diversion of flood waters.

CLOUD SEEDING. A method of weather modification in which clouds are injected with a seeding agent such as dry ice or silver iodide in order to enhance precipitation, clear fog, or inhibit the severity of storms.

CONJUNCTIVE USE. The coordinated use of surface and groundwater supplies. One technique is to recharge a groundwater basin during years of above-average precipitation so that the water can be withdrawn during years of below-average surface runoff.

CUBIC FEET PER SECOND. A basic unit for measuring the flow of water past a given point over time. Equivalent to 449 gallons per minute and 1.98 acre-feet per day.

DRAWDOWN. A lowering of the water level in an aquifer or reservoir.

EFFLUENT. Liquid or gas issuing from a contained space, as in the discharge of wastewater from a treatment plant.

ENTITLEMENT WATER. As used in connection with the State Water Project, the amount of project water made available at a delivery structure provided for the contractor under the terms of a contract with the state.

FLUME. An artificial water channel supported on or above the ground for the conveyance of water or materials such as logs or gravel.

HEADGATE. A gate, flap or valve at the entrance to a conduit, ditch, canal, or penstock which is used to control water flow.

HYDROGRAPH. A graphic representation of some property of water which is displayed with respect to time.

INSTREAM USE. A beneficial use of water in a stream channel as for recreation, fish and wildlife, navigation, the maintenance of riparian vegetation, or scientific study.

LEVEE. A ridge of material along a stream bank. A natural levee is formed by the deposition of sediment when a stream overtops its banks during a flood. An artificial levee, constructed of earth, rock or concrete, may be used to contain or direct water flow.

NAVIGABLE WATER. In general, any body of water which, during a substantial portion of the year, is capable of floating watercraft for purposes of trade, commerce, transport, or recreation. The United States Congress exercises regulatory authority over those navigable waters (and their tributaries) which are susceptible to use for trade and commerce. For purposes of defining ownership of stream and lake beds by the State of California, navigable water includes any body of water which was in fact navigable at the time of California's admission to the Union.

OUTFALL. The point, location, or structure where sewage or other drainage is discharged.

PERCOLATION. The movement of water through the interstices of soil or rock.

POINT SOURCE. Any discernable, confined and discrete conveyance from which pollutants are or may be discharged; this is distinguished from a non-point source, which is so general or covers so wide an area that no single, localized source can be identified.

RECLAMATION. As applied to land, the development or improvement of land through drainage, leaching to remove salts, flood control, or the provision of irrigation water. As applied to water, the treatment of wastewater so as to make it suitable for some beneficial use.

REIMBURSABLE COSTS. That portion of the cost of developing and distributing a water supply which the water users are held responsible to repay.

REPAYMENT PERIOD. The period of time prescribed for the payment of reimbursable costs. This period is commonly 40 or 50 years measured from a date specified in a contract for water delivery or from the time that the first services of a water project are made available.

RETURN FLOW. Any unconsumed water which returns to its source or some other water body after diversion from a surface water supply or extraction from a groundwater basin.

SAFE YIELD. As applied to groundwater, the maximum quantity of water that can be continuously withdrawn from a groundwater basin without producing an undesirable result. As applied to surface water, it is the maximum annual dependable supply from a water source during the driest period likely to occur.

SEDIMENTATION. The settling of solids in any body of water because of gravity or chemical precipitation.

SLOUGH. A creek in a marshland or tidal flat or an inlet from a river.

SPREADING. The application of water over areas of porous material in order to recharge an underlying groundwater basin.

STORAGE, CAPACITY. As applied to groundwater, total storage capacity is the amount of water that could potentially be extracted from a given depth of a totally saturated aquifer without regard to quality or economics; usable storage capacity, however, is the amount of water of acceptable quality that can be economically withdrawn from the aquifer. As applied to surface water, total storage capacity is the total amount that can be stored behind an impoundment structure or in a natural lake; usable storage capacity is the amount of water that can be drained through the lowest outlet of an impoundment structure.

TOTAL DISSOLVED SOLIDS. The quantity of minerals in solution in water, usually stated in nearly equivalent terms of parts per million (ppm) or milligrams per liter (mg/l).

TURNOUT. The point at which water is diverted from a main channel or water delivery facility to a distributing facility.

WATERSHED. The total land area that contributes water to a river, stream, lake, or other body of water. Synonymous with drainage area, drainage basin and catchment.

WATER YEAR. A continuous 12-month period within which hydrologic data is compiled and reported. In California, the water year starts on October 1, when groundwater and reservoir levels are usually at their lowest and the rainy season is about to begin.

WEIR. Any structure across a water course used to control, raise, or measure flows.

WETLAND. Any area in which the water table stands near, at, or above the land surface for at least part of the year. Such areas are characterized by plants that are adapted to wet soil conditions.

TO WHEEL. As applied to water and power, to provide the use of one agency's conveyance facilities for the purpose of transporting another agency's supply.

Metric Conversion Factors

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches	2.54	centimeters
	feet	0.3048	meters
	yards	0.9144	meters
	miles	1.6093	kilometers
Area	acres	0.40469	hectares
	square miles	2.5898	square kilometers
Volume	gallons	3.7854	liters
	acre-feet	1,233.5	cubic meters
	cubic feet	0.028317	cubic meters
Discharge	cubic feet per second	0.028317	cubic meters per second
	gallons per minute	3.7854	liters per minute
Weight (Mass)	pounds	0.45359	kilograms
	tons	0.90718	tons (metric)
Temperature	degrees Fahrenheit	$t\frac{F-32}{1.8}$	degrees Celsius
Electrical conductance	mho	1.0	siemens

CHAPTER 1

California's Water in Context

Numerous aspects of the urban, industrial and recreational uses of water are illustrated in this view of the east side of San Francisco Bay. Oakland is at the bottom of the photograph, Berkeley to the north, and the fringes of Lafayette can be seen at the far right. Intensive water use for vegetation in public parks, which appear here as vivid red, contrast markedly with the urbanized areas and watershed lands where the East Bay Municipal Utility District maintains its reservoirs.

Too many of us know only that water comes from the tap and then disappears down the drain. We trust that it will be available when we want it and that we can dispose of it without causing obvious pollution in our immediate surroundings. This lack of knowledge is unfortunate because water and its development for human use forms the basis of California's modern prosperity, the framework of our history, and the substance of our existence. Seventy-five percent of our body weight is water, and blood plasma is 90 percent water. Water is so important to our body functions that a loss of only 20 percent brings death. The inventive mind of man has developed no substitute for water in the production of food and fiber to sustain our lives. In our urban centers today, the use of water in homes averages 150 gallons per day for each person in the United States. Per capita use in California is generally greater than the national average and varies greatly with the season of the year, location and climate, and with the density and affluence of our population. During the winter months in high density neighborhoods, per capita use averages 100 gallons per day, but during the summer in the hot Central Valley, suburban dwellers may use as much as 660 gallons.

The amount of water we use directly in our homes, large though it may appear to be, is only a small fraction of the water used to produce our food and fiber, to provide manufactured goods, and to supply many of our other needs for such things as electrical energy. This overall use of water has climbed steadily from a per capita average of about 600 gallons daily in 1900 to 1,800 gallons in 1975. Water is the life blood of agriculture, California's largest industry. Assuming that approximately 1,600 pounds of food are produced to supply the 1,500 pounds consumed annually by a typical person and that an average of 1,000 gallons of water are needed to produce each pound of food, then it takes about five acre-feet of water to produce the food the average American consumes each year. The water requirements of food items in our diet, however, vary greatly. A pound of bread takes 136 gallons to grow the wheat, a pound of potatoes 23 gallons, a pound of tomatoes 125 gallons, and a pound of steak 2,500 gallons. In addition, one gallon of milk requires 932 gallons of water to grow the silage and alfalfa, water the cows, and clean the barns. Water is also an irreplaceable item in many manufacturing processes and the availability of water in adequate quantity and quality is necessary for economic growth and the standard of living we enjoy. As a result, we are coming increasingly to appreciate the essential role of water in our total environment and also the importance of our environment to human well-being and to the maintenance of numerous delicately balanced life-support systems which sustain us.

Water, however, makes up only one-tenth of one percent of the earth's mass and very little of the world's water can be used directly for human agricultural, industrial, and domestic needs. Ninety-seven percent of the world's water is in the ocean where it contains many dissolved and suspended materials. Of the remaining three percent, 2.2 percent is locked up in the polar ice caps, and three-tenths of one percent is too deep underground to recover and use. Less than one-half of one percent of all the water on earth can be used directly to support human life. Moreover, the earth's water supply is fixed; the quantity available is essentially the same now as it was more than five billion years ago when the planet was formed. Consequently, all the water we use is recycled. Every drop we drink, cook with, wash with, or use to irrigate our crops has been used countless times before.

Solar energy is the driving force behind this continuous recycling process. The sun, warming the surfaces of rivers, lakes, the ocean, and even the water in plants and the soil, agitates water molecules until their increased motion causes them to escape and be carried into the atmosphere by warm air currents. As these water molecules break away, they leave behind all minerals and other pollutants dissolved or suspended in the water. This is how our water is periodically cleaned for re-use. As these water molecules rise, they may be carried over land and mountains before they cool, condense into drops, and fall as rain or snow. Whether it occurs as rain or melting snow and ice, water immediately starts running downhill toward the ocean, first as streams, and then combined into rivers. Some is trapped in lakes and some percolates into groundwater basins. But it is this water, recycled and redistributed by nature, which we store, transport, pump, and use to sustain our lives on earth.

The size and power of this natural recycling and distribution system can be appreciated by a few simple comparisons. A single one-inch rainfall on a 160-acre farm delivers 4,356,000 gallons or 36,300,000 pounds of water. To transport this 18,150 tons of water would require 544 tank cars operating as four trains each over a mile long. To evaporate this amount of water from the ocean requires the equivalent of over a million horsepower of energy. Worldwide, about one-fourth of the total energy of sunlight is used to evaporate water, more than 4,000 times the total power now available to the world's industrialized civilizations. This water cycle is absolutely vital to the continuing renewal and purification of our water supply and thus it is essential to all life.

Nature does not, of course, distribute its freshwater supplies equally. In terms of water supply, California is made up of two very dissimilar areas: the northern portion shares characteristics with the more humid areas of Oregon and Washington while its southern half is a part of the most arid region in the United States. As a result, the total water supply in California is much less than that of many other regions of the nation with which California competes industrially and agriculturally. Although annual average precipitation per square mile in California is equivalent to 79 percent of the average for the entire United States, it is only 44 percent of the average per

California In Context

Population and Water Use

State	A	B	C	D
Arizona	7,000	7,800	211	2,360,000
California	35,000	51,000	185	22,018,000
Colorado	9,300	10,000	200	2,644,000
Idaho	15,000	17,000	236	855,000
Montana	11,000	12,000	267	764,000
Nevada	3,100	3,500	321	637,000
New Mexico	2,900	3,200	236	1,202,000
Oregon	6,000	6,900	190	2,373,000
Utah	3,500	4,100	331	1,264,000
Washington	5,500	7,200	256	3,697,000
Wyoming	6,800	7,200	191	407,000

A. *Irrigation water withdrawn (million gallons per day, 1975)*
B. *Water withdrawn from all sources, fresh and saline, except hydropower (million gallons per day, 1975)*
C. *Water withdrawn for public supplies from all sources (gallons per capita per day, 1975)*
D. *Estimated population 1978*

Selected Western Rivers

Average Annual Discharge (acre-feet)*

Stream	Gaging Station	Discharge
Columbia	The Dalles, Oregon	140,600,000
Snake	Clarkston, Washington	36,225,000
Willamette	Wilsonville, Oregon	20,540,000
Pend Oreille	Ione, Washington	20,540,000
Sacramento	Sacramento, California	17,870,000
Clark Fork	Cabinet, Idaho	15,920,000
Klamath	Klamath, California	12,900,000
Colorado	Compact Point, Arizona	12,860,000
Skagit	Mt. Vernon, Washington	12,000,000
Yellowstone	Sidney, Montana	9,353,000
Flathead	Polson, Montana	8,469,000
Salmon	White Bird, Idaho	8,013,000
Cowlitz	Castle Rock, Washington	6,618,000
Spokane	Long Lake, Washington	5,793,000
Umpqua	Elkton, Oregon	5,387,000
Eel	Scotia, California	5,379,000
Green	Green River, Utah	4,614,000
Rogue	Agness, Oregon	4,411,000
Deschutes	Biggs, Oregon	4,196,000
Trinity	Hoopa, California	3,958,000
Platte	South Bend, Nebraska	3,912,000
San Joaquin	Vernalis, California	3,197,000
Chehalis	Porter, Washington	3,018,000
Smith	Crescent City, California	2,819,000
American	Fair Oaks, California	2,765,000
Pit	Montgomery Creek, California	2,721,000
Bighorn	Bighorn, Montana	2,721,000
Payette	Payette, Idaho	2,199,000
Quinault	Quinault Lake, Washington	2,037,000
San Juan	Bluff, Utah	1,892,000
Yuba	Smartville, California	1,866,000
Gunnison	Grand Junction, Colorado	1,860,000
Coeur D'Alene	Cataldo, Idaho	1,827,000
Russian	Guerneville, California	1,712,000
Kings	Pine Flat Dam, California	1,624,000
Salmon	Somes Bar, California	1,331,000
Mad	Arcata, California	1,137,000

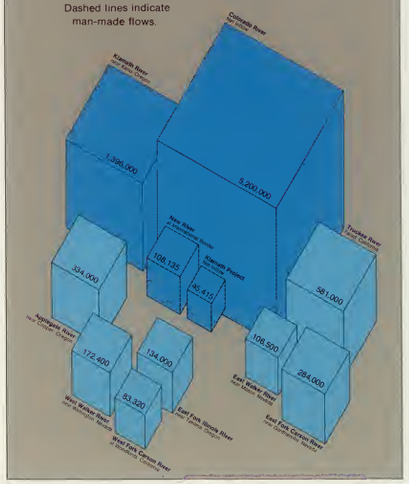
* *Average annual discharge to 1975 as shown for California rivers, to 1970 for other rivers, and for the period 1913-1962 for the Colorado.*

Selected Western Reservoirs

Reservoir	Stream	Capacity (acre-feet)
Lake Mead	Colorado	29,755,000
Lake Powell	Colorado	27,000,000
Fort Peck	Missouri	19,432,000
F. D. Roosevelt Lake	Columbia	9,562,000
Lake Koocanusa	Kootenai	5,809,000
Shasta Lake	Sacramento	4,552,000
Flaming Gorge	Green	3,789,000
Lake Oroville	Feather	3,538,000
Hungry Horse	Flathead	3,468,000
Dworshak	Clearwater	3,459,000
Lake Umatilla	Columbia	2,500,000
Clair Engle Lake	Trinity	2,448,000
Elephant Butte	Rio Grande	2,109,000
Canyon Ferry Lake	Missouri	2,051,000
San Luis	San Luis Creek	2,039,000
Don Pedro	Tuolumne	2,030,000
Lake Mojave	Colorado	1,818,000
Navajo	San Juan	1,709,000
American Falls	Snake	1,700,000
Riffe Lake	Cowlitz	1,685,000
Lake Berryessa	Putah Creek	1,602,000
Lake Pend Oreille	Pend Oreille	1,561,000
Brownlee	Snake	1,427,000
Ross Lake	Skagit	1,405,000
Palisades	Snake	1,400,000
T. Roosevelt Lake	Salt	1,382,000
Yellowtail	Bighorn	1,375,000
Tiber	Marias	1,369,000
Lake Wallula	Columbia	1,350,000
Lake Almanor	Feather	1,308,000
Banks Lake	Columbia	1,275,000
Abiquiu	Rio Chama	1,225,000
San Carlos	Gila	1,210,000
Strawberry	Strawberry	1,107,000
Alamo	Bill Williams	1,043,000
Lake McClure	Merced	1,026,000
Pathfinder	North Platte	1,016,000
Seminoe	North Platte	1,012,000
Folsom Lake	American	1,010,000
Pine Flat Lake	Kings	1,002,000

California Surface Inflows & Outflows

Average Annual Inflows (acre-feet)
Average Annual Outflows (acre-feet)



square mile in the South Atlantic and East Gulf states. And while the average annual runoff in California is more than nine times that of the Colorado River Basin as a whole, it is eqivalent to only 51 percent of the average runoff per square mile in the Ohio River Basin and 36 percent of the annual averages that obtain in New England.

California is, however, unique in many ways. It has a 1,072-mile coastline on the Pacific Ocean which greatly moderates its climate, affects its water supply and use, and provides a sink for outflows from rivers and streams and from our agricultural and urban developments. The state is essentially cut off hydrologically by mountains from its neighboring states to the east. Consequently, except for some inflows from Oregon, small outflows to Nevada, and the significant quantities of water from the Colorado River which California shares with other states and Mexico, our water supply is essentially independent of other states.

Precipitation is the principal source of California's water supply. The state's average annual precipitation is about 200 million acre-feet. Two-thirds of this total falls on the northern one-third of the state. About 65 percent of this precipitation is lost by evaporation directly into the atmosphere leaving only 71 million acre-feet for the average annual runoff in streams. Forty percent of this runoff or 28 million acre-feet occurs in north coastal streams; 31 percent or 22 million acre-feet in the Sacramento River system; nine percent or seven million acre-feet in the San Joaquin River system; and 20 percent or 14 million acre-feet is scattered over the rest of the state. Approximately one-fourth of the total average runoff or 18 million acre-feet is now protected from development under the state's wild and scenic rivers program.

Groundwater is an important adjunct to the natural supply provided by surface streamflows. The vast groundwater basins which underlie the Central Valley and other areas of the state have an estimated total capacity of 1.3 billion acre-feet with a usable capacity some estimate to be as high as 143 million acre-feet. In years of normal rainfall, groundwater supplies 40 percent of the water used in the San Joaquin Valley. In the drought year 1977, however, groundwater provided about 80 percent of agriculture's needs when 9,000 new wells were drilled in this valley alone. Statewide, more than 20,000 new wells were brought into production in 1977, further aggravating the serious overdraft or mining of California's groundwater. During recent years of average precipitation, groundwater overdraft has approximated two million acre-feet; the groundwater overdraft in 1977, however, has been variously estimated at four to ten million acre-feet. Overdraft in future dry years could go higher unless steps are taken. Failure to control such overdrafts will increase energy requirements for pumping, decrease water availability, produce water of poorer quality, encourage saltwater intrusion along the shores of saline bays and the ocean, and bring about significant and sometimes serious land subsidence.

Views on water development and use are changing. Historically, Californians have developed and used water so as to minimize constraints on the growth of our cities and irrigated agriculture. Nature may have intended much of California's now highly populated areas and most productive croplands to be brown, but we have turned them green with produce or gray with concrete according to our will. More recently, however, we have come to realize that water is itself a limited resource. The emphasis today is not so much upon water development as upon water management. What this alteration in our attitudes will mean for the future of California cannot easily be predicted. But the situation clearly calls for increasing scrutiny of the reasonableness or efficiency of present water uses.

There is considerable misunderstanding about water use. The term "use" sometimes refers to the total quantities diverted from surface water sources or pumped from groundwater. Alternatively, it may be applied to mean only that portion of the supplied water which becomes unavailable for further use by being lost in evaporation from water, soil, or plant surfaces or incorporated into plant tissue or into manufactured goods. Accordingly, some water uses are non-consumptive and others are consumptive. More than half the water delivered to California's irrigated farms, on the average, is lost to the atmosphere by evaporation from soil and transpiration by plants. Evaporation from soil can be partially controlled by the installation of efficient irrigation systems and management practices. But the process of evapotranspiration from plant leaves remains largely uncontrolled and presents, therefore, a tremendous challenge to those seeking efficient conservation. Water use in homes, except that lost to the air in irrigating plants, is generally non-consumptive. Typically, more than 90 percent of the water used in homes is degraded and disposed of down the drain. Similarly, water delivered to most industrial plants is used non-consumptively to convey, wash, cool, or heat materials. Most of this water becomes effluent and remains a part of the state's water supply. But pollution itself can be equivalent to a consumptive use when the water becomes so degraded that the treatment necessary for its re-use may not be technically or economically feasible and its discharge to the ocean or other sink is consequently the most practical solution to the problem of its disposal.

In terms of withdrawals, 87 percent of California's developed water is taken for irrigation; 8.5 percent for domestic, commercial, and institutional uses; 2 percent for manufacturing; and about 2.5 percent for other purposes. But in terms of consumptive use, 91 percent goes for irrigation, 5 percent for domestic and related uses, one percent for manufacturing, and about 3 percent for others. By the year 2000, the portion used consumptively by irrigation is expected to decline slightly to 89 percent accompanied by small increases in municipal and industrial uses.

Predictions of water use are highly controversial, however, due to uncertainties about projected population levels and our inability to predict the domestic and international markets for various agricultural products as well as other changes related to crop production. Based on four population alternatives and four alternative levels of crop production, it has been estimated that present water diversions will increase from about 37 million acre-feet today to 41-46 million acre-feet by 1990 and 43-55 million acre-feet by 2020. An unquantified amount of water will also be needed to provide instream flows for fish and wildlife, to preserve wetlands for birds, and to protect water quality in areas such as the Sacramento-San Joaquin Delta and the San Francisco Bay.

How can water be managed so as to meet as fully as possible the needs of diverse and legitimate interests at all levels and in all geographic areas? There are no easy answers. Sound water policy and action programs require that account be taken not only of the scientific and technical aspects of water management but also of the numerous historic, economic, social, environmental, legal, institutional, and political interests involved. The sections of the atlas that follow treat these many factors and their interrelationships in detail. Only through enlightened public understanding of these complex issues can we hope to integrate divergent viewpoints and contending interests into a wise policy of water management which will have sufficient resiliency to cope with climatic change and other developments in our society which could substantially alter California's efforts to achieve a balance between water supply and water demand.